The Indian River Lagoon as a bioreactor: new perspectives on sewage pollution

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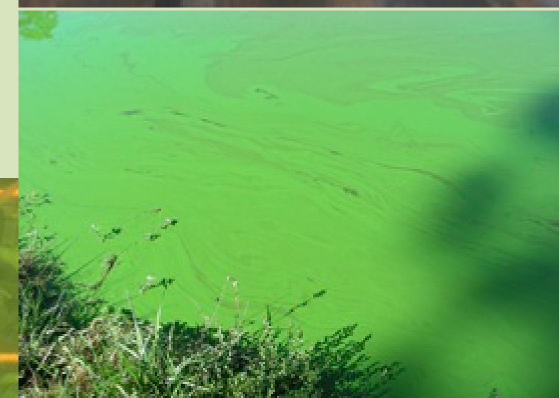
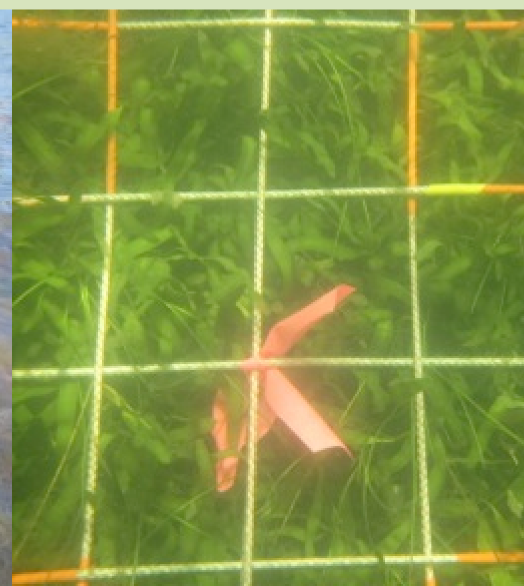
Critical Issues Facing the IRL

- Excessive freshwater releases
- Nutrient, microbial and contaminant pollution
- Harmful algal blooms
- Loss of seagrass habitat
- Decline of fisheries
- Emerging diseases and mortalities in wildlife (manatees, dolphins, sea turtles, pelicans, fish, shellfish)





Controlled Eutrophication: Integrated, Multi-Trophic Aquaculture (IMTA) in the 1970s

- Pilot-scale research at Woods Hole and HBOI to demonstrate feasibility of recycling human sewage through aquaculture systems;

- Open, linear, flow-through systems included phytoplankton ponds, shellfish raceways, deposit feeders, fish, and macroalgae as the final "polishing step;"

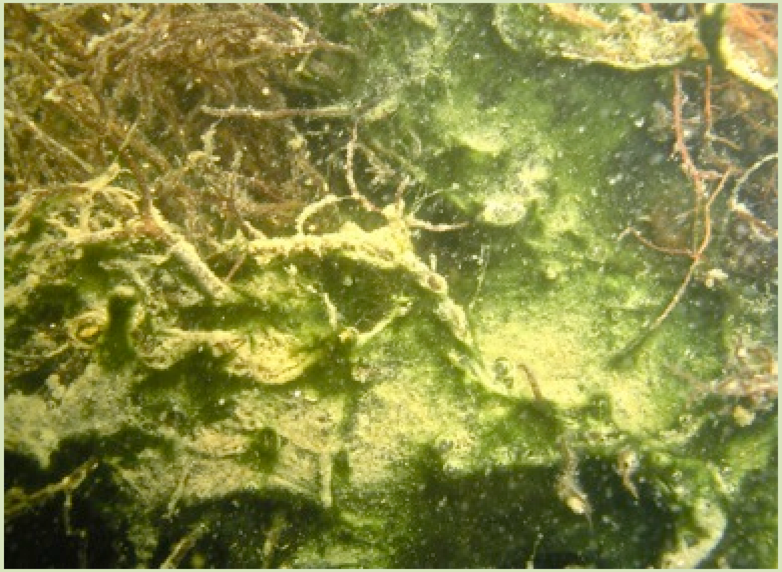
- Growth of the red seaweed *Gracilaria* was very rapid on seawater/sewage mixtures;

- Demonstrated success of fast-growing seaweeds to remove nutrients in aquaculture systems.

Macroalgal Blooms Expand in South Florida's Coastal Waters

Lee County

IRL



Changing Land-Use and Eutrophication in the IRL

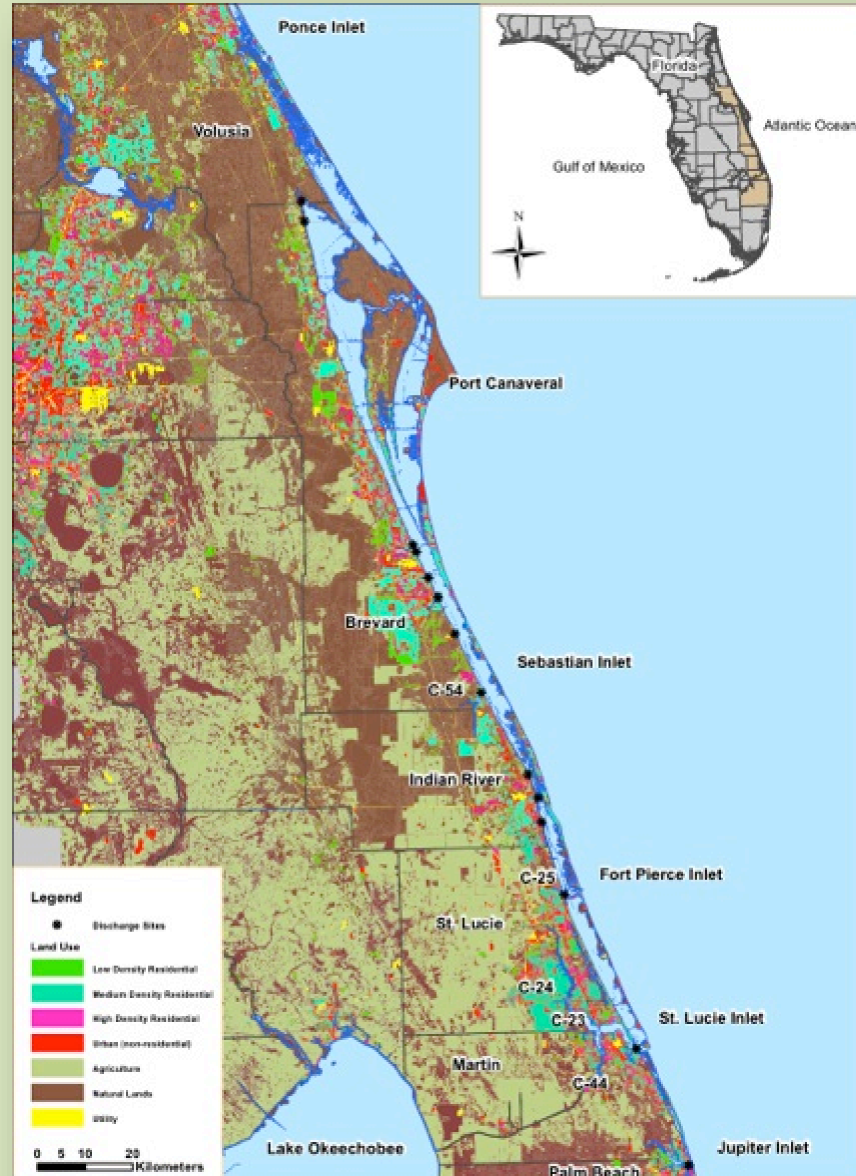
- Land-Use

urban	39%
agriculture	24%
forest	4.5%
wetland	12.1%
range	20.8%

- Eutrophic Condition

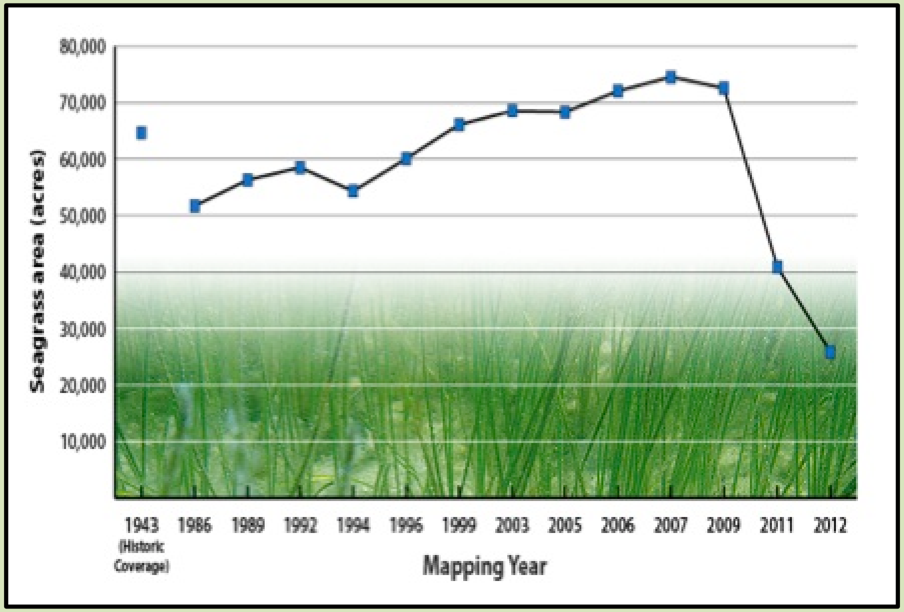
  Moderate to high nitrogen input
  High susceptibility (low flushing)
  Substantial expression of eutrophy
  Algal blooms likely to worsen

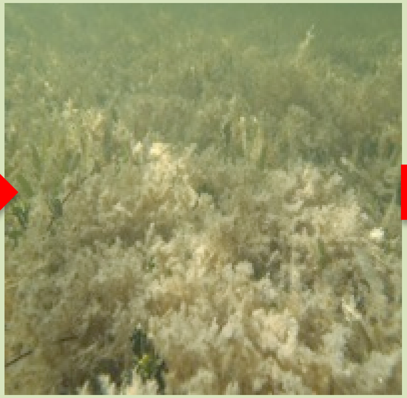
From: Bricker et al. 2007 National Estuarine Eutrophication Assessment, NOAA, Silver Springs, MD



Ecosystem Responses to Eutrophication in the IRL

- Increasing seagrass epiphytes, macroalgae, and phytoplankton
- "Super Bloom" followed multi-year drought in 2011
- Brown Tide in 2012
- Unprecedented seagrass die-off
- Wildlife, fish, shellfish mortality in IRL





Point- and Non-Point Source Sewage Pollution

• IRL Act 1990 eliminated sewage outfalls but not septic tanks (OSTDS)

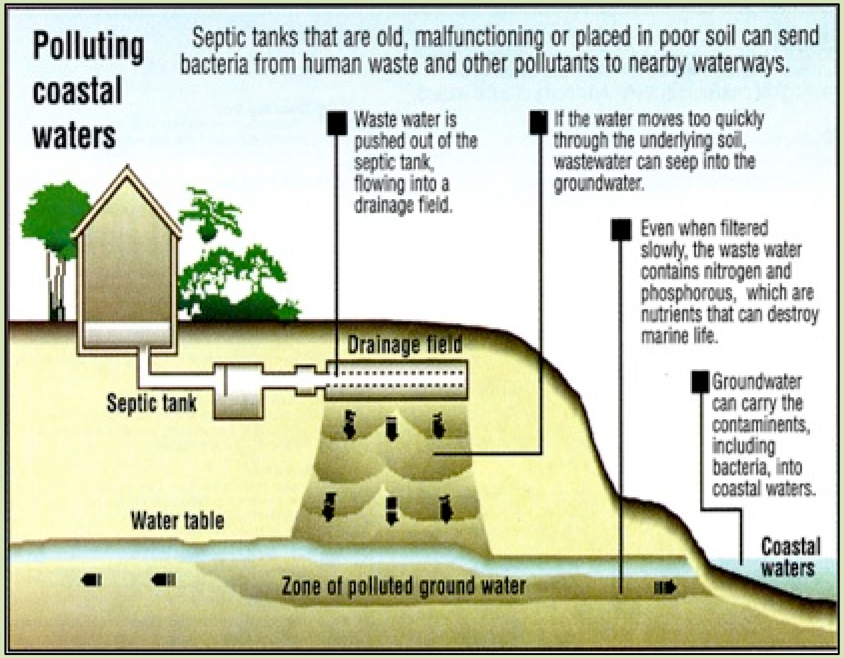
• ~ 300,000 known OSTDS exist on IRL watersheds

• Soils on IRL watersheds are unsuitable for OSTDS

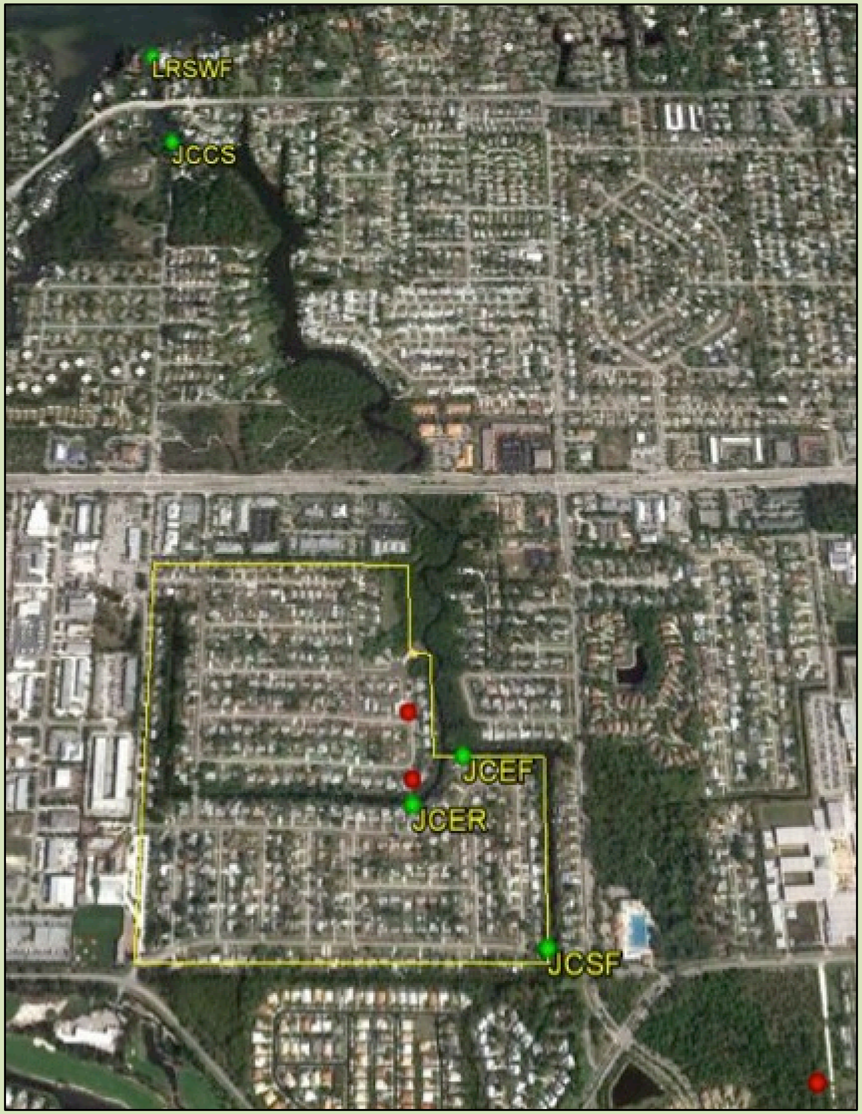
• Contaminants include nitrogen, phosphorus, OWCs (pharmaceuticals, hormones, etc.), bacteria, viruses

• Assuming 2.5 people/OSTDS, estimated N-load is ~ 2,575 tons N/yr

• High mercury in IRL marine mammals and fish linked to OSTDS?



Jupiter Creek Septic Tank/Water Quality Study in 1995: Loxahatchee River District



Results of Jupiter Creek Study

- Interaction of groundwaters and Jupiter Creek influenced by tidal pumping, elevated groundwater tables in wet season

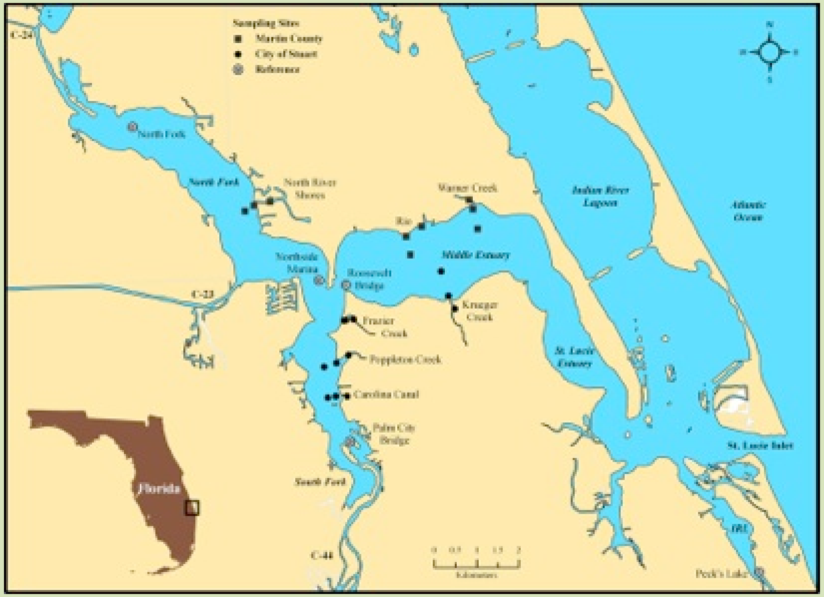
- "Failing" septic tanks caused ammonium buildup in groundwaters and Jupiter Creek

- $\delta^{15}N$ values (o/oo) in shallow groundwaters and Jupiter Creek > + 3 o/oo, characteristic of sewage

- Higher fecal coliforms in wet season compared to dry season in both groundwaters and Jupiter Creek

- High concentrations (> 1,000 ug/kg) of coprostanol, a fecal sterol, present in "black mayonnaise" sediments

St. Lucie Estuary Study: 2005-2006



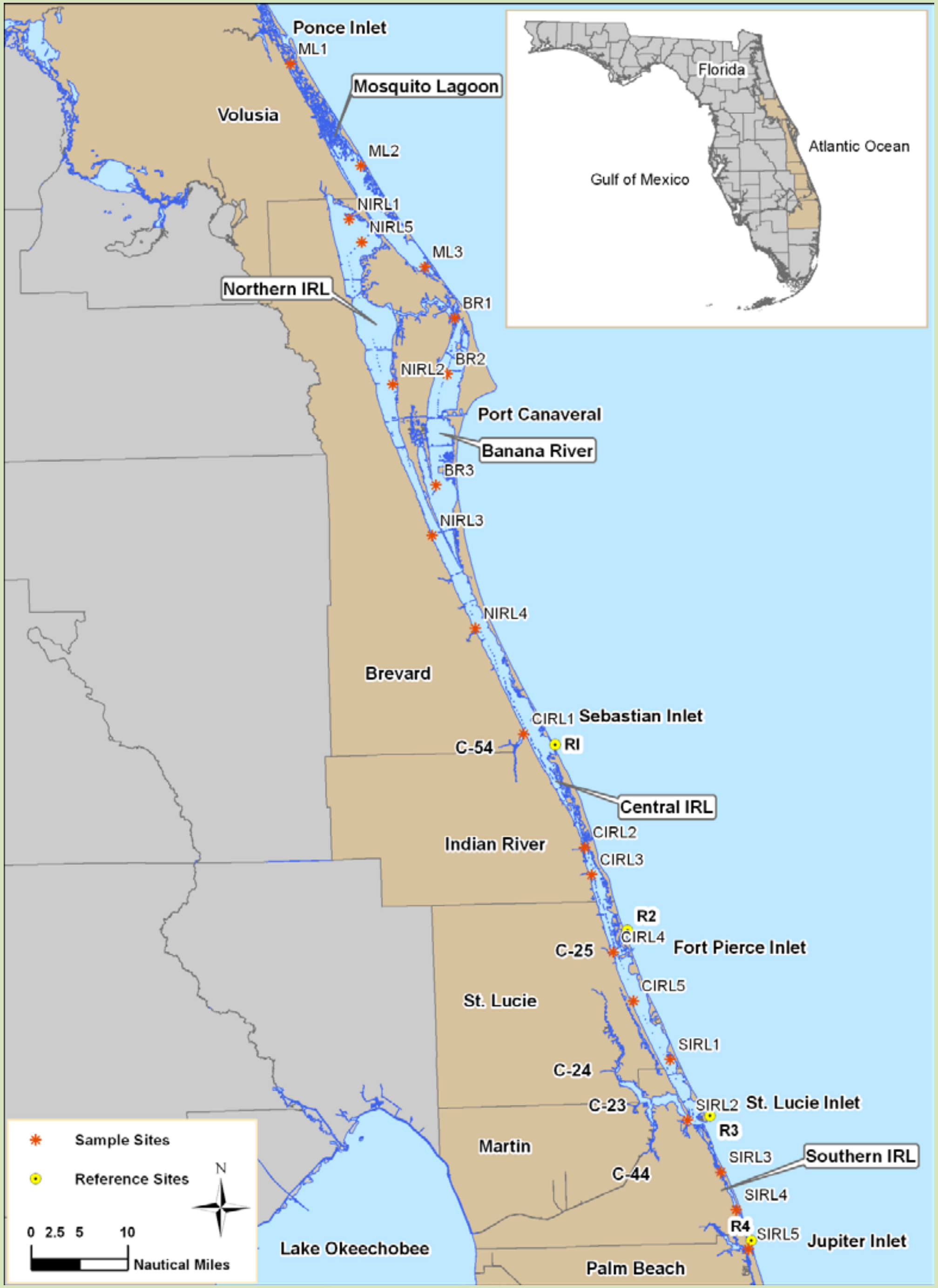
- Sampled in June & November 2005, March 2006
- Freshwater discharges caused low salinity and DO, high nutrients, turbidity, coliforms
- Highest turbidity, nitrate, and TN in South Fork (C-44); ammonium and phosphate highest in North Fork (C-23, C-24)
- Highest nutrients and coliforms near residential areas with high densities of septic tanks
- Toxic *Microcystis* blooms in Manatee Pocket in 2013 had high $\delta^{15}N$ values (+ 8.6 $^{o}/_{oo}$) in the range of sewage nitrogen

IRL-Wide Study 2011-2012

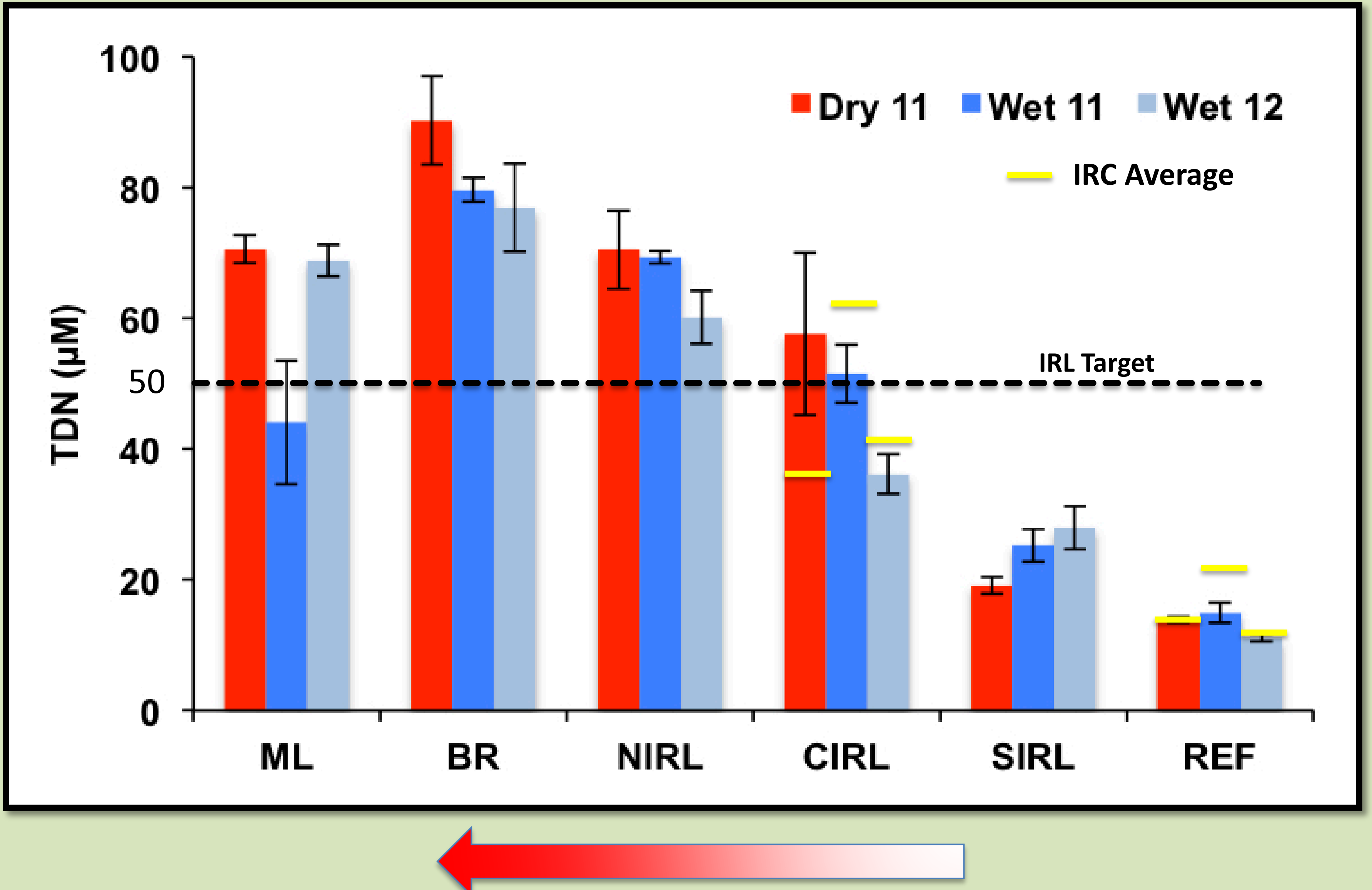
20 IRL Sites + 4 Reference Sites

• Objectives: Use multiple lines of evidence (dissolved nutrients, C:N:P and $\delta^{15}N$ in macroalgae) to assess spatial/temporal patterns in nutrient pollution, N- vs. P-limitation of algal growth, and N sources fueling eutrophication in the IRL.

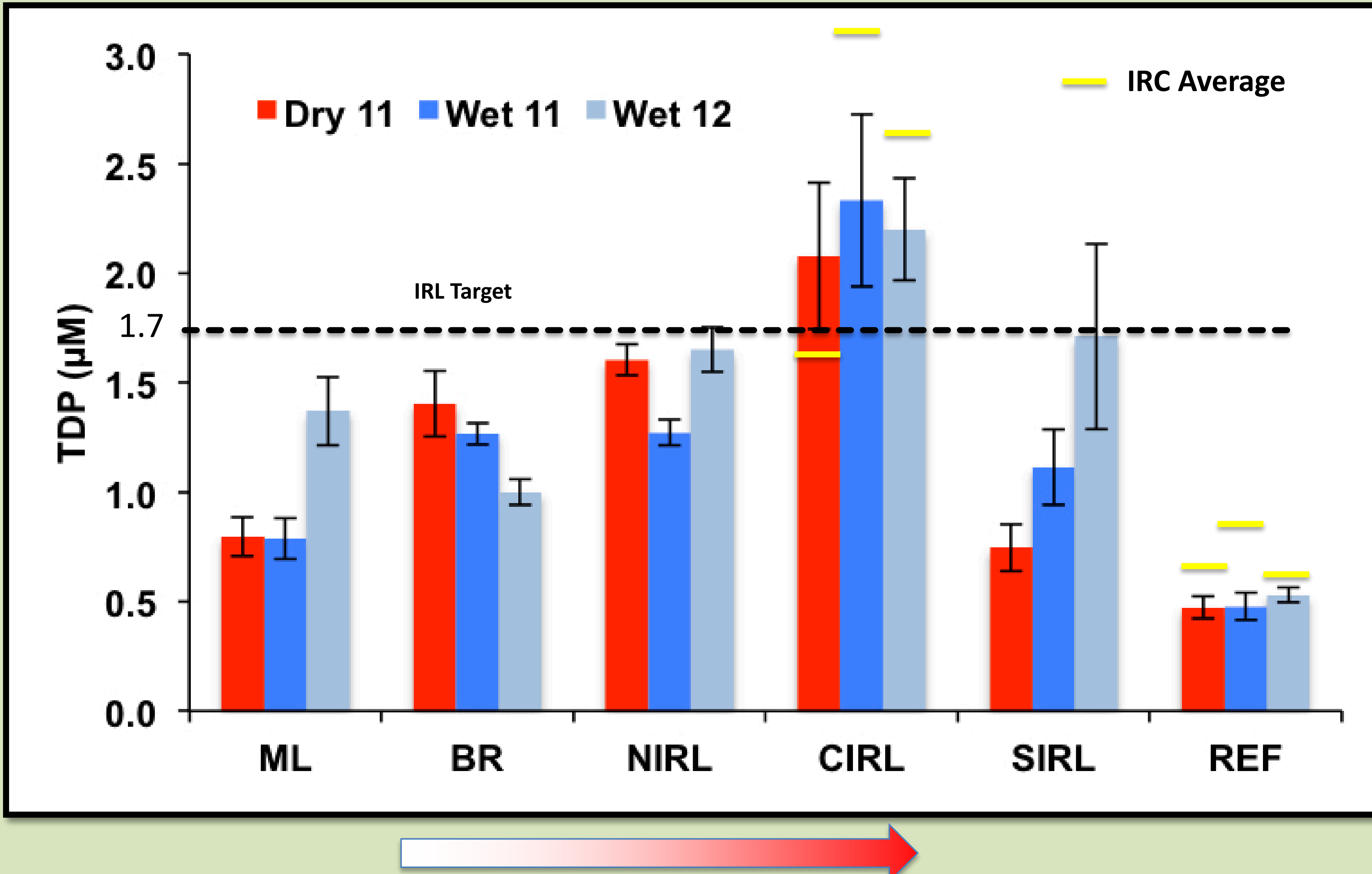
• Goal: Improve water quality in the IRL by providing high-quality, user-friendly data to resource managers and policy-makers.



TDN (Total Dissolved Nitrogen)



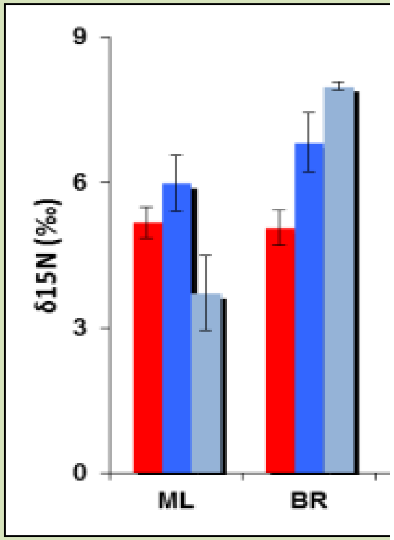
TDP (Total Dissolved Phosphorus)

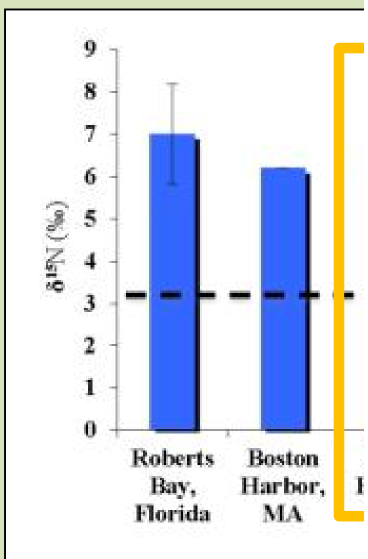


Macroalgae as Bio-Observatories in the IRL

Gracilaria tikvahiae		***Caulerpa prolifera***	
Hypnea musciformis		*Hypnea spinella*	
Caulerpa mexicana		*Laurencia filiformis*	
Acetabularia schenckii		*Acanthophora spicifera*	

Stable N Is ... ge N Source





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Evidence of sewage-driven eutrophication and harmful algal blooms in Florida's Indian River Lagoon

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ABSTRACT

Nutrient pollution is a primary driver of eutrophication and harmful algal blooms (HABs) in estuaries and coastal waters worldwide. In 2011–2012, 20 sites evenly distributed throughout the 251-km long Indian River Lagoon (IRL) were assessed during three sampling events for dissolved nutrients (DIN, SRP, TDN, TDP) and chlorophyll *a*. Benthic macroalgae were also analyzed for δ^{13}C, δ^{15}N, and C:N:P contents to identify potential nutrient sources and gauge the type and degree of N and P limitation. The mean DIN and SRP concentrations throughout the IRL were high, averaging 4.24 ± 0.45 and 0.68 ± 0.06 μM, respectively, explaining the widespread occurrence of HABs during the study. High TDN concentrations (up to 152 μM) and TDN:TDP ratios (>100:1) in the poorly flushed northern IRL, Mosquito Lagoon and Banana River segments reflected the accumulation and cycling of N-rich groundwater inputs that produce P-limitation. These enriched nutrient conditions were associated with unprecedented chlorophyll *a* concentrations (>100 μg/L), dominated by *Resultor* sp. Ø. Moestrup in the Banana River in 2011 and *Aureoumbra lagunensis* D.A. Stockwell, DeYoe, Hargraves and P.W. Johnson in the Mosquito Lagoon and northern IRL in 2012. C:N, C:P, and N:P ratios in macroalgae averaged 15.9, 698.9, and 40.6, throughout the IRL, respectively; significantly higher C:P and N:P ratios in the northern IRL segments suggested strong P-limitation in these N-enriched waters. Macroalgae δ^{15}N values were enriched throughout the IRL (+6.3‰) and similar to values reported for macroalgae from other sewage-polluted coastal waters. Because point-source sewage inputs to the IRL were largely eliminated through the IRL Act of 1990, these results suggest that non-point source N enrichment from septic tanks (~300,000) represents a significant and largely ignored N-source to the IRL. The high degree of sewage N contamination of the IRL, combined with recent HABs, including toxic ecotypes of the red macroalga *Gracilaria tikvahiae* McLachlan, seagrass loss, and wildlife mortality, indicates a critical need for improved sewage collection and treatment, including nutrient removal.

1. Introduction

Coastal and estuarine ecosystems are among the most productive ecosystems in the world, providing invaluable ecological services to human populations. However, many of these ecosystems are being degraded as a result of expanding human activities such that their ability to sustain future societal needs is now at risk. Humans have greatly increased the concentrations of nitrogen (N) and phosphorus (P) in freshwaters flowing into the coastal zone (Nixon, 1995; Vitousek et al., 1997; MEA, 2005), exacerbating eutrophication and habitat loss (NRC, 2000; Bricker et al., 2007). As a result, nutrient enrichment is now a major agent of global change in coastal waters, linking an array of problems along coastlines, including eutrophication, biodiversity loss, harmful algal blooms (HABs), "dead zones," emerging marine diseases, fish kills, and loss of seagrass and coral reef ecosystems (NRC, 2000; Howarth and Marino, 2006; Rockström et al., 2009).

Located along Florida's east-central coast, the Indian River Lagoon (IRL) is a shallow (mean depth ~0.8 m) and narrow (~3 km wide) bar-built estuary extending 251 km between Jupiter and Ponce inlets (Steward and VanArman, 1987; Fig. 1). Because the IRL comprises a transition zone between temperate and subtropical biomes, the IRL is considered a regional-scale ecotone and one of the most species-diverse estuaries in North America (Swain et al., 1995). The basin includes the Mosquito Lagoon (ML) and Banana River (BR), which are located in the northern regions of the IRL. The climate of the IRL basin is humid subtropical with distinct dry and wet seasons. Rainfall within the basin averages 140–150 cm/yr,

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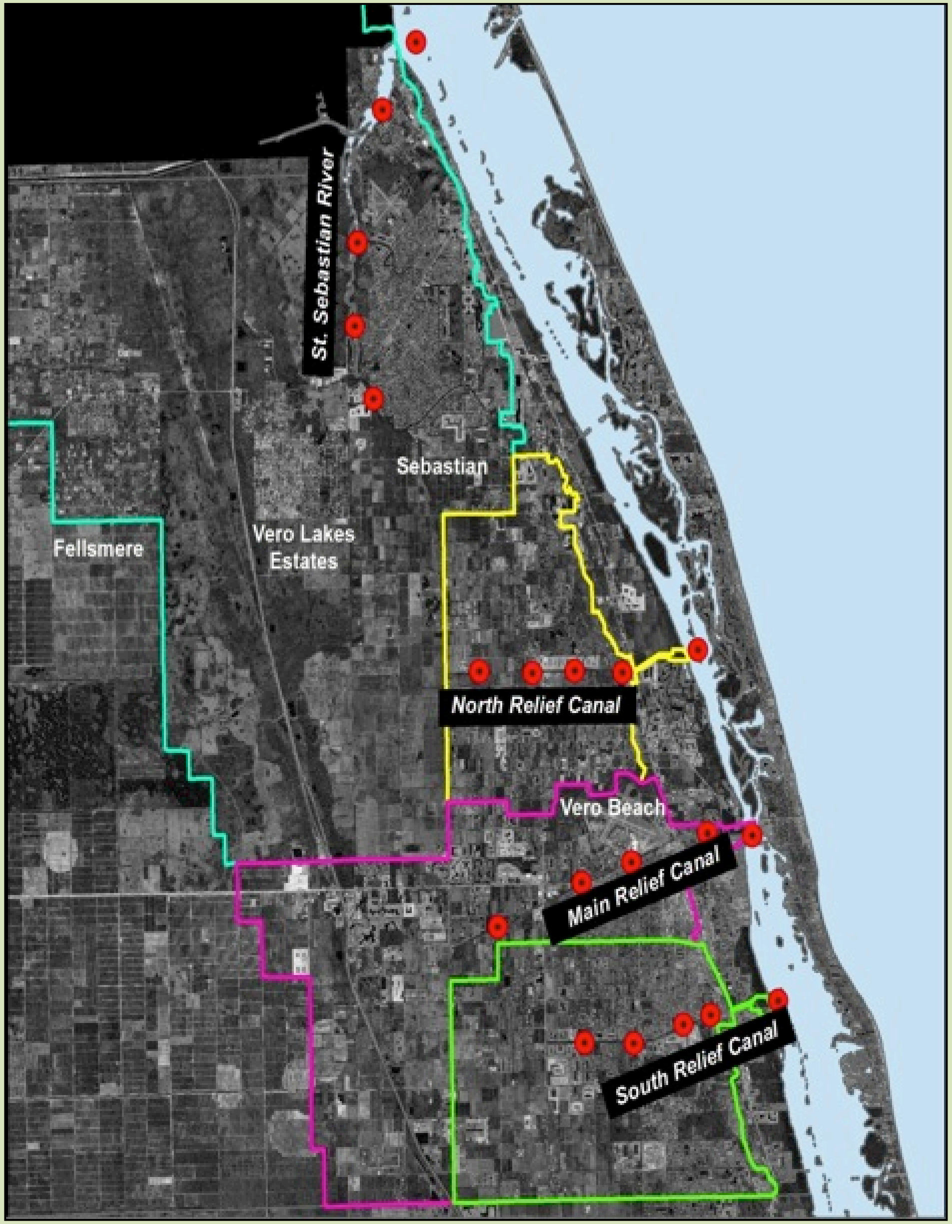
δ^{15}N Level
+3 to +5
+5 to +28
+2
0
-3 to +2
-2 to +2
0 to +2

...d + 6.3 ‰

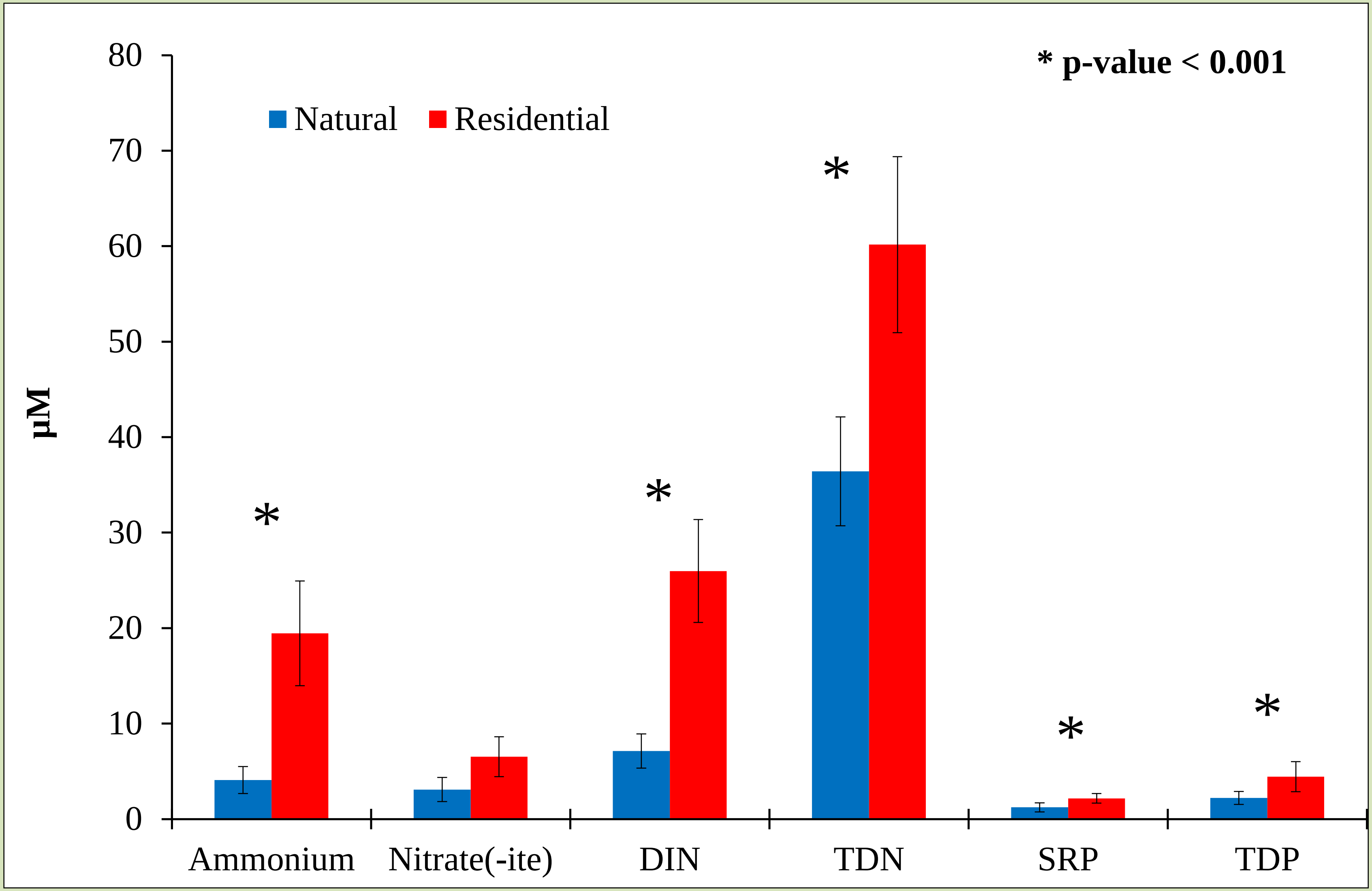
...able to other
...sewage

Indian River County Sampling

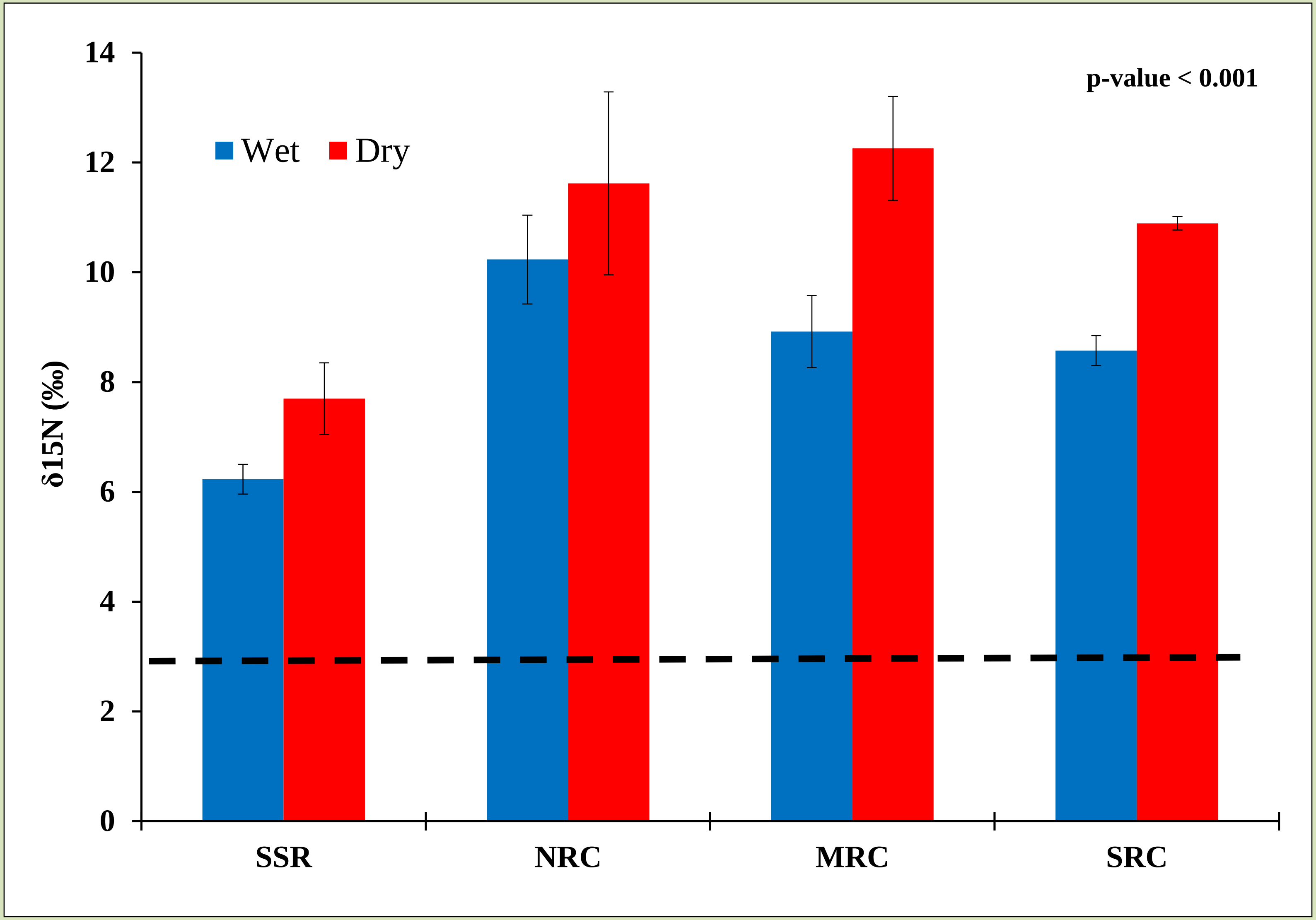
- October 2013 (wet season)
- March 2014 (dry season)
- Surface water
- Groundwater
- Reference Sites



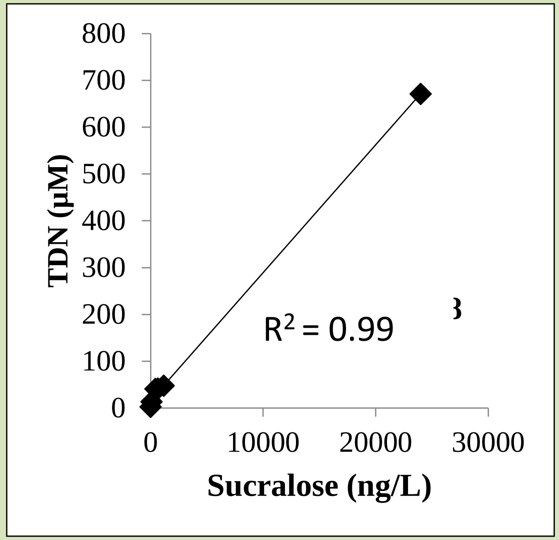
Dissolved N and P Levels in Natural Vs. Residential Areas

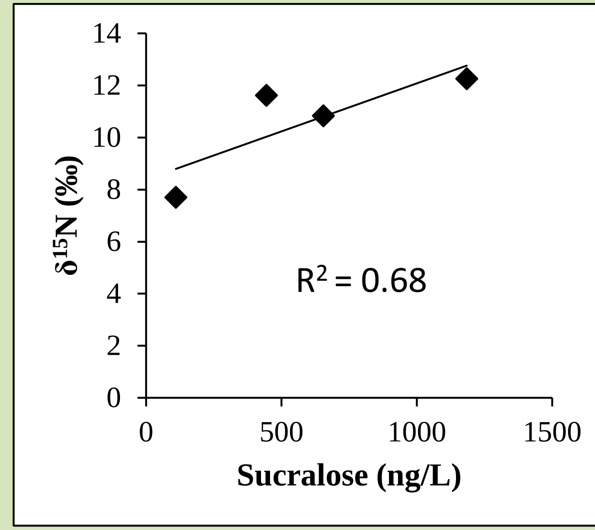


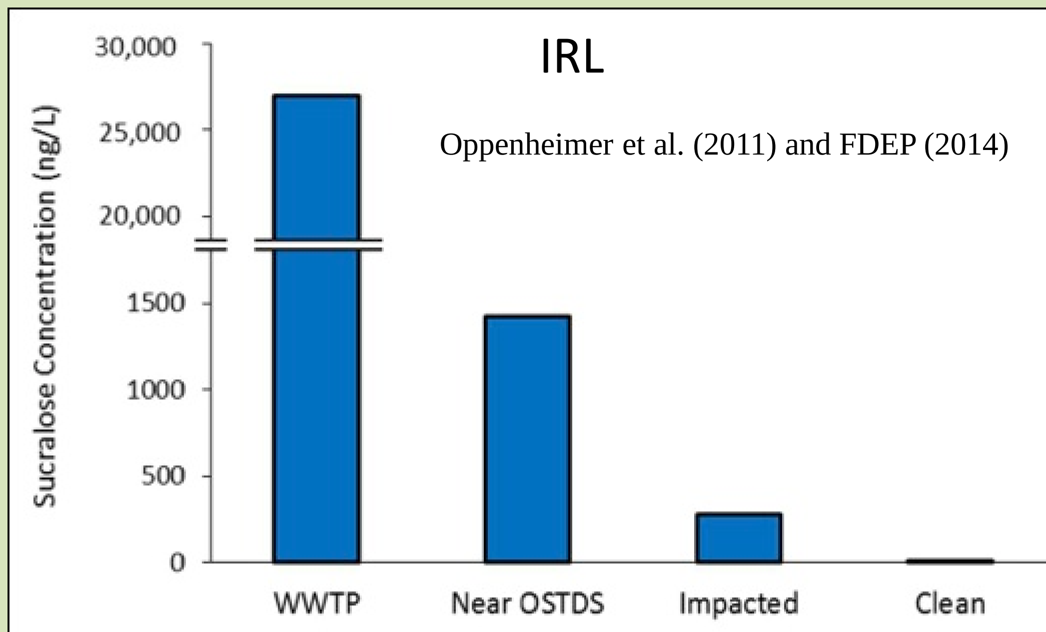
Macrophyte δ^{15}N

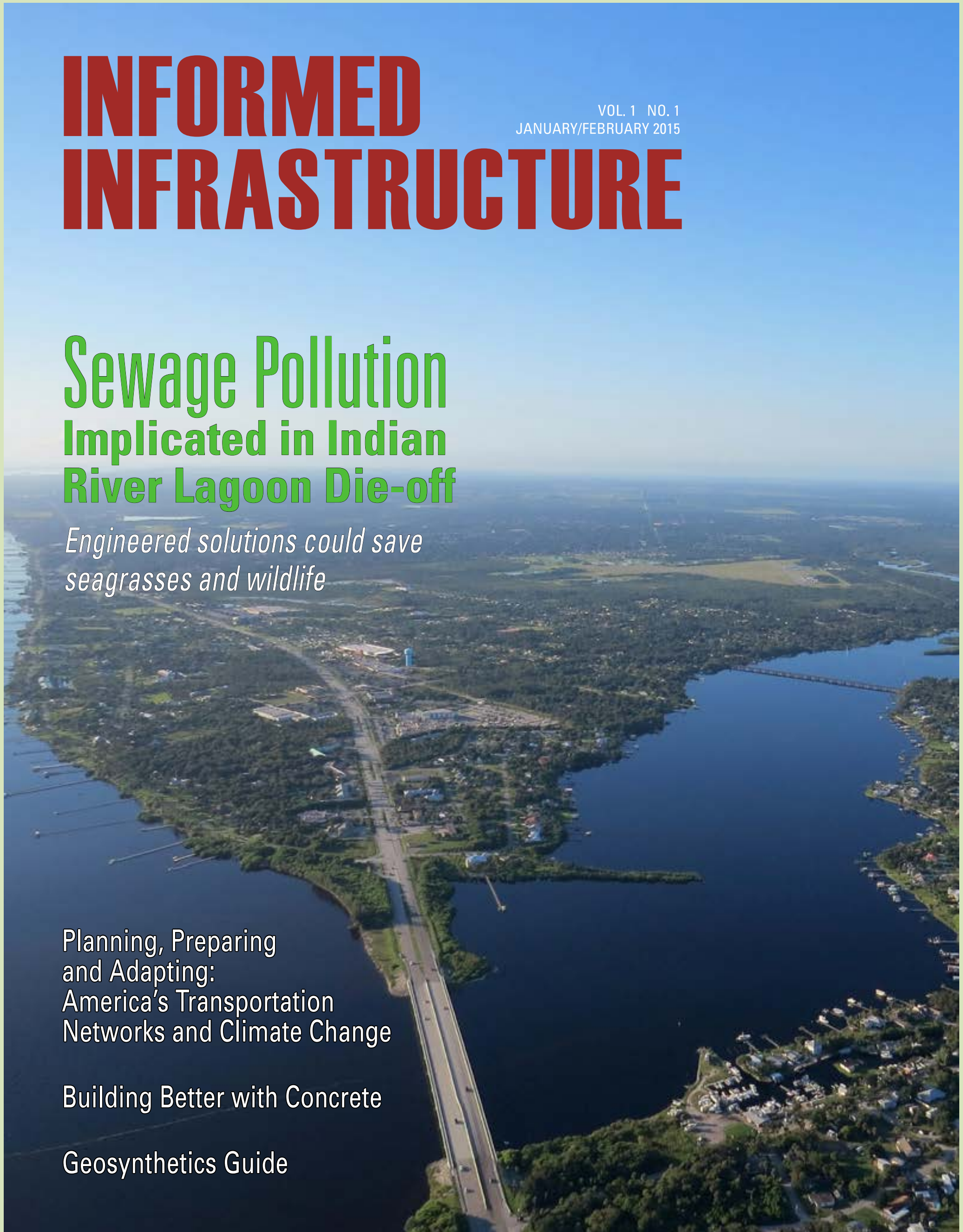


A Human Tracer: Sucralose









Moving Forward

- Septic tanks do not protect IRL water resources
- This is an inadequate infrastructure problem on watersheds of IRL
- Action plan to implement OSTDS language of 1990 IRL Act?
- Septic tank reductions as part of BMAPs?

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